

## Comparison of the Semantic Networks in Patients With Dementia and Amnesia

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The semantic networks of 13 patients with Alzheimer's disease (AD), 13 patients with Huntington's disease (HD), 8 amnesic (AM) patients, and 26 controls were generated by multidimensional scaling and Pathfinder analyses of their responses on a triadic comparison task. The semantic networks of HD and AM patients were essentially normal, whereas the networks of AD patients were deviant in a number of ways. The AD patients' networks were dominated by a different dimension, had fewer common links, and consisted of associations of atypical strength. These results suggest that structural alteration of semantic networks is characteristic of Alzheimer's disease and is not evident in all forms of dementia and amnesic conditions.

Investigations of the language deficits of patients with Alzheimer's disease (AD) on confrontation naming (Bayles & Tomoeda, 1983; Hodges, Salmon, & Butters, 1991) and verbal fluency tasks (Martin & Fedio, 1983; Monsch et al., 1994; Tröster, Salmon, McCullough, & Butters, 1994) have suggested that the structure of their semantic knowledge may be disrupted (Martin, 1987). To examine the specific nature of this disruption, researchers are now studying the organization of semantic knowledge in AD patients with multidimensional scaling (MDS) and cluster analyses that have permitted the generation of participants' cognitive maps (i.e., semantic spaces; Chan, Butters, Paulsen, et al., 1993; Chan, Butters, Salmon, & McGuire, 1993). In an initial study using animal fluency data (Chan, Butters, Paulsen, et al., 1993), the dimensions and clusters that characterize participants' cognitive maps were determined by calculating the proximity of concepts (e.g., *dog* and *cat*) in each participant's verbal output. An

analysis of these maps indicated that the semantic space of AD patients was poorly organized and characterized by three uninterpretable clusters. In contrast, the cognitive maps of normal controls and patients with Huntington's disease (HD) displayed two well-organized clusters based on recognizable dimensions of *domesticity* and *size*.

Consistent with this finding of abnormal clusters, a second investigation (Chan et al., 1993) showed that AD and elderly normal controls (ENC) use dimensions differently in organizing the concepts comprising their semantic space. A three-dimensional cognitive map was generated for participants from their responses on a triadic comparison task. On this task, three animal names (e.g., *dog*, *cat*, or *tiger*) were presented to participants and they were asked to choose the two most similar animals in the triad. Multidimensional analyses of the choices made on this triadic comparison task showed that the participants' cognitive maps were organized along the dimensions of *predation*, *domesticity*, and *size* and that the AD patients' semantic structure was significantly different than that of ENC participants in two ways. First, AD patients were less consistent than ENC participants in using dimensions to categorize concepts. Second, AD patients focused primarily on a concrete perceptual dimension (i.e., *size*) to organize their semantic space, whereas ENC participants stressed abstract conceptual knowledge (i.e., *domesticity*) for this purpose.

Although this second study (Chan et al., 1993) indicated that AD patients organize their semantic space along different dimensions than elderly normal individuals, the specific MDS techniques used did not yield a quantitative index of the strength among the various concepts comprising the semantic network. To remedy this situation, we used the Individual Difference Scaling Analysis (INDSCAL) to generate cognitive maps and also introduced another graphic methodology called Pathfinder analysis (Dearholt & Schvaneveldt, 1990) to examine both the strength of the associations comprising the semantic networks and the number of common links in the networks of patients and intact controls. Based on pairwise

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proximity data, this Pathfinder analysis can generate a graph in which concepts and associations between concepts are represented by nodes and links, respectively.

A second aim of this study was to compare the semantic space of AD patients with those of other demented and amnesic patients. Although the first author and her colleagues (Chan et al., 1993) interpreted the distorted semantic network of AD patients as reflecting a disruption of semantic memory that may arise from extensive damage to temporal and parietal association cortices (Katzman & Jackson, 1991), the possibility remains that the distortion may be due to other factors, such as general cognitive impairment, retrieval failure, or a deficit in episodic memory. To address these possibilities, we compared the performance of amnesic and HD patients with those of the AD patients reported by Chan et al. (1993).

If the semantic network disruption of AD patients is due to deterioration of semantic knowledge and not to these unrelated factors, then the semantic networks of amnesic and HD patients should be essentially normal. Although amnesic patients are well-known to be impaired on episodic memory tests, they usually perform normally on semantic memory tasks such as the Vocabulary and Information subtests of the Wechsler Adult Intelligence Scale—Revised (WAIS-R; Squire & Zola-Morgan, 1991). In contrast to amnesics, HD patients often manifest impairments on such semantic tasks when their knowledge is assessed under free-recall conditions (Butters, Wolfe, Martone, Granholm, & Cermak, 1985; Butters, Granholm, Salmon, Grant & Wolfe, 1987). However, because their performance improves dramatically (and to a much greater extent than AD patients) when recognition procedures are used, the HD patients' deficits in the recall of semantic (as well as episodic) information has been interpreted as a failure in retrieval from a relatively intact semantic network (Butters et al., 1987; Monsch et al., 1994).

On the other hand, if the disruption of AD patients' semantic networks is related to factors such as global cognitive impairment, retrieval failure, or deficits in episodic memory, then amnesic and/or HD patients may also manifest distorted networks because both groups suffer episodic memory impairment and HD patients are globally demented with a general retrieval deficit (Heindel, Salmon, & Butters, 1993).

## Method

### Participants

Thirteen patients with the clinical diagnosis of probable AD (6 women and 7 men), 13 patients with HD (5 women and 8 men), 8

amnesic patients (3 women and 5 men), 13 middle-aged normal control (MNC) participants (7 women and 6 men) and 13 ENC participants (7 women and 6 men) participated in this experiment. The diagnosis of AD, made by a senior staff neurologist at the University of California, San Diego (UCSD) Alzheimer's Disease Research Center (ADRC), met criteria developed by the National Institute of Neurological and Communicative Disorders and Stroke (NINCDS) and the Alzheimer's Disease and Related Disorders Association (ADRDA; McKhann et al., 1984). To reduce the possibility of including participants with multi-infarct dementia, we excluded patients with a score of 5 or greater on the modified Hachinski Ischemia Scale (Hachinski et al., 1975) from the AD patient group. The AD patients in this study were the same patients as in Chan et al. (1993).

The HD patients were diagnosed by a senior staff neurologist on the basis of a positive family history of the disease, the presence of involuntary choreiform movements, and the presence of dementia. Amnesic patients were recruited from Veterans Affairs medical centers in Boston and San Diego. An extensive neuropsychological examination indicated that severe anterograde and retrograde memory impairments were the major cognitive deficits exhibited by the amnesic patients. Whereas the WAIS-R Full Scale IQ of the amnesic patients ranged from 90 to 136 with a mean of 105, their Wechsler Memory Scale-Revised (WMS-R) General Memory Index scores ranged from 76 to 90 with a mean of 79. Their average Delayed Memory Index score from the WMS-R was 57 (range 50 to 65). Four of the amnesic patients had alcoholic Korsakoff's syndrome (Butters & Cermak, 1980); the other 4 amnesic participants included 2 anoxic patients, 1 postencephalitic patient, and 1 patient with a closed head injury.

Both middle-aged and elderly normal controls were either spouses of patients or volunteers obtained through newspaper advertisements. Individuals with a history of alcoholism, drug abuse, learning disabilities, and serious neurological or psychiatric illness were excluded from the control groups. The 13 ENC participants in this study were the same individuals in Chan et al. (1993).

Table 1 shows the age, years of education, and Dementia Rating Scale (DRS) scores (Mattis, 1976) of the ENC, MNC, AD, HD, and amnesic groups. The years of education, age, and DRS among the participant groups were compared with Scheffé multiple *t* tests. The comparison of years of education showed no significant differences (all *ps* > .05) among the five groups of participants. The DRS scores of AD and HD patients did not differ significantly, but their scores were significantly (all *ps* < .05) lower than those of the ENC, MNC, and amnesic participants. Although the AD and ENC participants did not differ significantly in age, they were significantly older (all *ps* < .05) than the MNC, HD, and amnesic participants. The latter three groups were not significantly different in terms of age. To rule out the effect of age, we compared the cognitive maps of HD and amnesic patients with those of the MNC participants, whereas the maps of AD patients were compared with those of the ENC participants.

Table 1  
Age, Years of Education, and Dementia Rating Scale Scores (*M* ± *SD*) for Elderly (ENC) and Middle-Aged (MNC) Normal Controls and Patients With Alzheimer's Disease (AD), Huntington's Disease (HD), and Amnesia

Variable	ENC	MNC	AD	HD	Amnesic
Age (years)	76 ± 5.5	49 ± 13.0	73 ± 4.4	49 ± 12.8	60 ± 14.3
Education (years)	14 ± 2.2	14 ± 2.4	14 ± 3.8	13 ± 2.3	15 ± 3.1
Dementia Rating Scale score	142 ± 1.7	143 ± 1.3	120 ± 10.0	125 ± 10.9	132 ± 4.5

Note. *n* = 13 for all groups except for amnesic patients, where *n* = 8.

## Stimuli

**Triadic comparison task.** Twelve high-frequency animal names (bear, cat, cow, dog, elephant, giraffe, horse, lion, pig, rabbit, tiger, and zebra) were chosen according to the norms provided by Battig and Montague (1969). Those animal names are also among the 30 most frequent responses of AD patients on the animal fluency task (Chan, Butters, Paulsen, et al., 1993). The stimuli were presented in a fixed random order three at a time in the form of an equilateral triangle on a computer screen. There were 220 trials representing all possible permutations (i.e., orderings and combinations), with the 12 animal names taken three at a time.

**Word-picture matching task.** The stimuli consisted of black-and-white drawings of the 12 animals used in the triadic comparison task. The size of each picture was about 7 cm<sup>2</sup>, and the pictures were mounted individually on 9 cm<sup>2</sup> pieces of cardboard. The label (name) of each target animal was also mounted individually on a 2 × 9 cm piece of cardboard. This task was administered to ensure that all participants could recognize the animals used in the triadic comparison task.

## Procedure

All testing was individual, and sessions took place in a quiet testing room. The triadic comparison task, presented on a Macintosh IICI computer with a monitor, was administered first. On each of the 220 trials, three animal names were presented on the computer screen, and the participant was asked to indicate the two animals that were most alike. The examiner recorded the participant's response by touching on the interface the corresponding icons representing the selected words. Once the participant's response had been recorded, another triad was presented on the screen. The entire testing was divided into four sessions (55 trials each) with 5-min rest intervals between sessions.

Immediately following completion of the triadic comparison task, the word-picture matching test was administered. This task required participants to match the 12 animal names to the 12 animal pictures. First, the drawings of the 12 animals, three rows of 4 in a row, were placed on the table directly in front of the participants. The placement of the drawings was randomly assigned. The 12 animal names were then handed to the participants one at a time. On each trial, the participants were asked to match the animal name with one of the drawings on the table. After the participants had given a response, the examiner placed the name of the animal under the chosen picture and recorded the response as correct or incorrect. During the task, the participant was allowed to make corrections; however, all corrections were recorded and scored as errors. The total number of correct responses was calculated at the end of the task.

## Statistical Analyses

Both MDS and Pathfinder techniques were chosen for analyzing the data because each procedure has unique advantages and limitations. Whereas MDS revealed the dimensions underlying the organization of semantic knowledge by providing a continuous visual configuration of the distribution of the concepts, Pathfinder analysis yielded a quantitative measure of the strength of the associations among the concepts in the network.

Individual Difference Scaling Analysis (INDSCAL), a MDS method developed by Carroll and Chang (1970), was chosen for analyzing the proximity data derived from the triadic comparison task. INDSCAL not only provides an overall group semantic space (i.e., a cognitive map

representing the proximity data for a given group of participants) like other MDS analyses but also accounts for individual differences with regard to the saliency of each dimension. The relative saliency of each dimension to an individual participant is represented by a *weight index*. The higher the weight index the more important the dimension is for that participant. Moreover, a *skewness index* indicating the distribution of saliency among dimensions (or how consistent the participant is in using the dimensions) was also computed for each participant. A participant with one high weight and many low weights will have a skewness index score near 1, and a participant with many average weights will have an index approaching 0 (see Davison, 1983; Romney, Shepard, & Nerlove, 1972; Shepard, Romney, & Nerlove, 1972, for general discussion of MDS). The accuracy of the MDS solution in representing the proximity data was measured by the stress value (Kruskal's Stress Formula 1) and the linear variance accounted for by each solution (*R-square*). In general, the smaller the stress value, the smaller the error; the larger the *R-square*, the more accurate the solution.

Pathfinder analysis (Dearholt & Schvaneveldt, 1990) shares the goal of MDS in reducing large amounts of proximity data to an interpretable form. However, unlike MDS, a Pathfinder analysis generates a network representation of the concepts rather than a continuous configuration. A Pathfinder network consists of a set of nodes with each node representing a concept. The strength of the associations between two nodes represented by an index is determined by the proximity data. That is, a pair of concepts with a low proximity estimate (*value*) will have a long distance (i.e., *high index*) between them, whereas a pair of concepts with a high proximity value will have a short internode distance (i.e., *low index*). Two concepts are directly connected in the network, if and only if the distance of their direct link is shorter than all their indirect links in the network.

Knowledge Network Organizing Tool (KNOT; Interlink) was used for generating Pathfinder networks based on pairwise proximity data. The Pathfinder analysis allows the user to choose the level of complexity (i.e., number of links) by adjusting two functions in the calculation. The first function, *r*, defines the path length and the second function, *q*, determines the maximum number of links in the path. From the same set of data, the Pathfinder analysis can generate the simplest network with a minimum number of links, the most detailed network with the maximum number of links, or a network with a number of links between the simplest and the most complex ones. The complexity of the network as a function of the *r* value is illustrated by the algorithm

$$D_{ab(r)} = \left[ \sum_{i=1}^k |X_{ai} - X_{bi}|^r \right]^{1/r},$$

where  $D_{ab(r)}$  = the path length between *a* and *b*,  $X_{ai}$  = the value of coordinate for point *a* in dimension *i*,  $X_{bi}$  = the value of coordinate for point *b* in dimension *i*, and *k* = the number of dimensions.

As shown by the algorithm, when  $r = 1$ , the path weight is the sum of link weights along the path of point *a* and point *b* (city block metric). For  $r = \text{infinite}$ , the path weight of point *a* and *b* is the maximum weight associated with any link along the path. With  $r = 2$ , the path weight is computed the same way as Euclidean distance. As a result, as the value of *r* decreases, the number of links in the resulting network increases. Thus, with  $r = \text{infinite}$ , Pathfinder produces a network with minimal connections. For  $r = 1$ , Pathfinder generates the most detailed (complex) network defined by the proximity data (Dearholt & Schvaneveldt, 1990). The choice of the complexity in a network should be based on the theoretical assumptions or the practical purposes of the experiments. When studying the organization of concepts, researchers should consider the complex network, which can provide detailed

information regarding the associations in the network and should, therefore, better reflect the latent structure of the semantic network.

## Results

### Picture-Matching Task

On the word-picture matching task, the percentage correct for each participant was calculated, and group means were then derived by averaging the scores of the individual participants comprising the group. The resulting mean percentage correct for the ENC (100%), MNC (100%), AD (99%), HD (99%), and amnesic (100%) groups indicated that virtually all of the participants could identify the 12 animals with high accuracy.

### Cognitive Maps of MNC, HD, and Amnesic Participants

*Middle-aged normal controls.* Thirteen  $12 \times 12$  matrices, one from each participant, were analyzed by INDSCAL. Each number (*proximity index*) in a matrix represents the frequency that two animal names were chosen as most alike. Because Kruskal and Wish (1978) proposed that the accuracy of a map in representing the proximity data may decrease significantly if the number of stimuli is smaller than four times that of the dimensions ( $S < 4D$ ), the present data (consisting of 12 stimuli) can be analyzed in either two- or three-dimensional solutions. When preliminary solutions were computed for two and three dimensions, the variances accounted for by the two-dimensional and the three-dimensional solutions were 86% and 89%, respectively. The stress value, a measurement of errors suggested by Kruskal and Wish (1978), was used to evaluate how good the solution is in representing the proximity data. The stress value of the two-dimensional map was 0.21 and of the three-dimensional map 0.16.

The two-dimensional solution was chosen for further analyses for the following reason. The third dimension only accounted for 8% of the variance. Given this relatively poor goodness-of-fit level, it is not surprising that the third dimension could not be interpreted with any obvious known attribute. As Kruskal and Wish (1978) wrote, "... when too many dimensions are used, the configuration adapts itself to the random error in the data, and this may actually make it more difficult to find the valid and interesting aspects" (p. 57). With interpretability as a primary criteria (Kruskal & Wish, 1978), the three-dimensional solution was rejected. It should be noted that the three-dimensional solution accounted for only 3% more variance than did the two-dimensional solution, and the third dimension was not used heavily by any participant. Within the two-dimensional solution, the percentages of variance accounted for by the first and second dimensions were 59% and 27%. The cognitive map (also known as the group stimuli space) of the MNC participants is represented in Figure 1A. The first dimension appeared to be *domesticity* with domestic animals on one side and wild animals on the other side. The second dimension seemed to order the animals in terms of *size* with *elephant* at one extreme and *cat* at the other end. Because the dimension of *domesticity* accounted for a major proportion of variance (59%), it was more salient than the dimension of *size* in organizing animals.

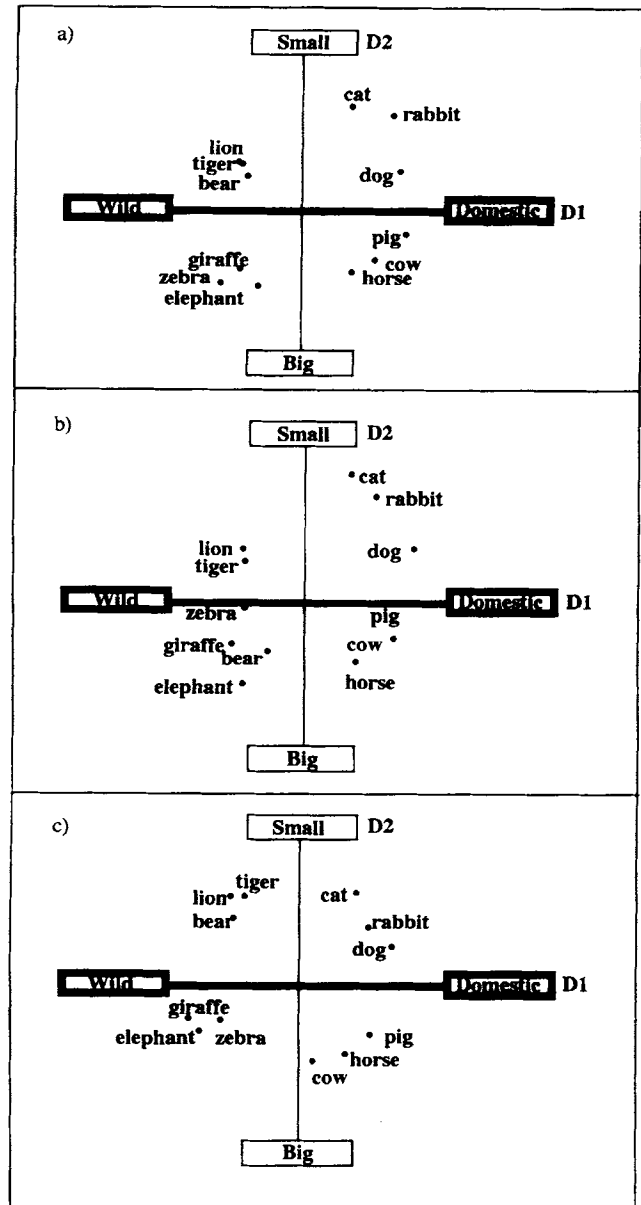


Figure 1. Cognitive maps of (a) 13 middle-aged normal controls, (b) 13 Huntington's disease patients, and (c) 8 amnesic patients. Cognitive maps were generated by Individual Difference Scaling Analysis based on the proximity data obtained from a triadic comparison task. The most salient dimension the participants used in categorizing concepts is represented in bold outline.

*Patients with Huntington's disease.* The 13 matrices, one from each HD patient, were also analyzed by INDSCAL. Preliminary solutions were again computed for two and three dimensions, and the variances accounted for by the two- and three-dimensional solutions were 74% (stress value = 0.21) and 78% (stress value = 0.16), respectively. The two-dimensional solution was chosen for further analyses for the same reasons mentioned previously. That is, the third dimension accounted only for 9% of the variance and adding this

dimension made it more difficult to interpret the configuration. The proportion of variance accounted for by the first dimension was 54% and by the second dimension was 21% (see Figure 1B). Visual inspection suggested that the first dimension (D1) ordered animals in terms of *domesticity*, and the second dimension (D2) organized animals in regard to *size*. These results suggest that HD patients, like MNC participants, organized animals based on the dimensions of *domesticity* (the first dimension) and *size* (the second dimension). As suggested by the relative proportion of variance accounted for by the two dimensions, the dimension of *domesticity* appeared to be the most salient organizational tendency.

*Amnesic patients.* The matrices of the amnesic patients were analyzed by INDSCAL for two- and three-dimensional solutions. The variances accounted for by the two- and three-dimensional solutions were 80% (stress value = 0.18) and 84% (stress value = 0.13), respectively. Because the third dimension was not emphasized by any participant and did not increase the variance accounted for to a great extent, the two-dimensional solution was chosen for further analysis. The proportion of variance accounted for by the first dimension was 60% and by the second dimension was 20%. The cognitive map (see Figure 1C) of amnesic patients seems to organize animals in terms of *domesticity* in the first dimension and by *size* in the second dimension. These results suggest that amnesic patients, like the MNC participants, organized animals along the dimensions of *domesticity* and *size*, with the dimension of *domesticity* being the most salient organizational tendency.

#### Comparisons of the Cognitive Maps of HD and Amnesic Patients With Those of MNC Participants

To compare statistically the relative saliency of dimensions in the cognitive maps of the individual MNC and the HD participants, we used INDSCAL to analyze the 13 matrices of the MNC participants to obtain the initial configuration and participant weight indices. The 13 matrices of the HD patients were then analyzed and compared with the initial configuration. Weight indices for each dimension were calculated for each participant by the MDS program. The algorithm used in the calculation assumes that all participants used the same dimensions and differed only in terms of the relative importance among the different dimensions. The skewness index, a measure of consistency in using the different dimensions, was also computed for each participant.

The participant weights and skewness indices were compared by three planned *t* tests. Table 2 shows the mean skewness index and the mean weights of the first and second

dimensions for the MNC and HD participants. The mean skewness index of the HD patients was not significantly different from that of the MNC participants,  $t(24) = 0.23$ , *ns*. Similarly, the HD patients' mean weights for the first and the second dimensions were not significantly different from those of the MNC participants,  $t(24) = 0.15$ , *ns*, for the first dimension and  $t(24) = 0.75$ , *ns*, for the second dimension.

The cognitive maps of MNC and amnesic participants were compared in the same manner. The results indicated that the mean skewness indices of the MNC and amnesic participants (see Table 2) were not significantly different  $t(19) = 2.18$ , *ns*. The mean weight of the first dimension for amnesic patients (see Table 2) was not significantly different,  $t(19) = 0.16$ , *ns*, than that of MNC participants. The mean weights of the second dimension for MNC and amnesic participants (see Table 2) were not significantly different,  $t(19) = 1.81$ , *ns*. These statistical comparisons suggest that the MNC, HD, and amnesic participants organized the animals using the same dimensions.

A discriminant function analysis was used to discriminate the three participant groups using the skewness indices, and the weight indices of dimensions 1 and 2 as dependent variables. The results indicated that these three variables did not significantly discriminate among the participant groups,  $\chi^2(N = 2) = 1.1$ , *ns*.

#### Summary of Chan et al.'s (1993) Comparison of the Cognitive Maps of AD Patients and ENC Participants

Because the following data have been reported previously by Chan et al. (1993), only a brief summary is presented here. According to the criteria suggested by Kruskal and Wish (1978), the semantic networks of both ENC and AD participants were best represented by a three-dimensional solution (see Figure 2). The three dimensions were interpreted as *domesticity*, *predation*, and *size*. Domesticity proved to be the most salient dimension in the cognitive maps of the ENC participants, whereas size proved to be the most salient dimension in the cognitive maps of the AD patients. A discriminant function analysis was used to compare the cognitive maps of ENC and AD participants based on the weight indices for each of the three dimensions and the skewness indices (see Table 3). The Wilks's lambda test indicated that the ENC participants' mean skewness index was significantly higher than that of the AD patients, and the mean weight of the third dimension for AD patients was significantly higher than that of the ENC participants. These findings suggested that ENC participants are more consistent than AD patients in using dimensions for categorizing concepts and that AD patients stress the third dimension (i.e., size) more than do ENC participants. It should also be noted that these results cannot be attributed to some random performance by the AD patients because their participant weights and skewness indices in the initial test and in a 1-week retest were highly stable (Chan et al., 1993).

It should be noted that the results obtained from MDS suggested that there was an age effect in the organization of semantic knowledge. That is, younger individuals used fewer

Table 2  
Participant Weights ( $M \pm SD$ ) on Two Dimensions and Skewness Index

Weight	MNC	HD	Amnesia
Dimension			
1	0.74 $\pm$ 0.21	0.64 $\pm$ 0.20	0.77 $\pm$ 0.09
2	0.48 $\pm$ 0.21	0.41 $\pm$ 0.18	0.36 $\pm$ 0.16
Skewness index	0.36 $\pm$ 0.19	0.36 $\pm$ 0.19	0.24 $\pm$ 0.16

Note. MNC = middle-aged normal control; HD = Huntington's disease.

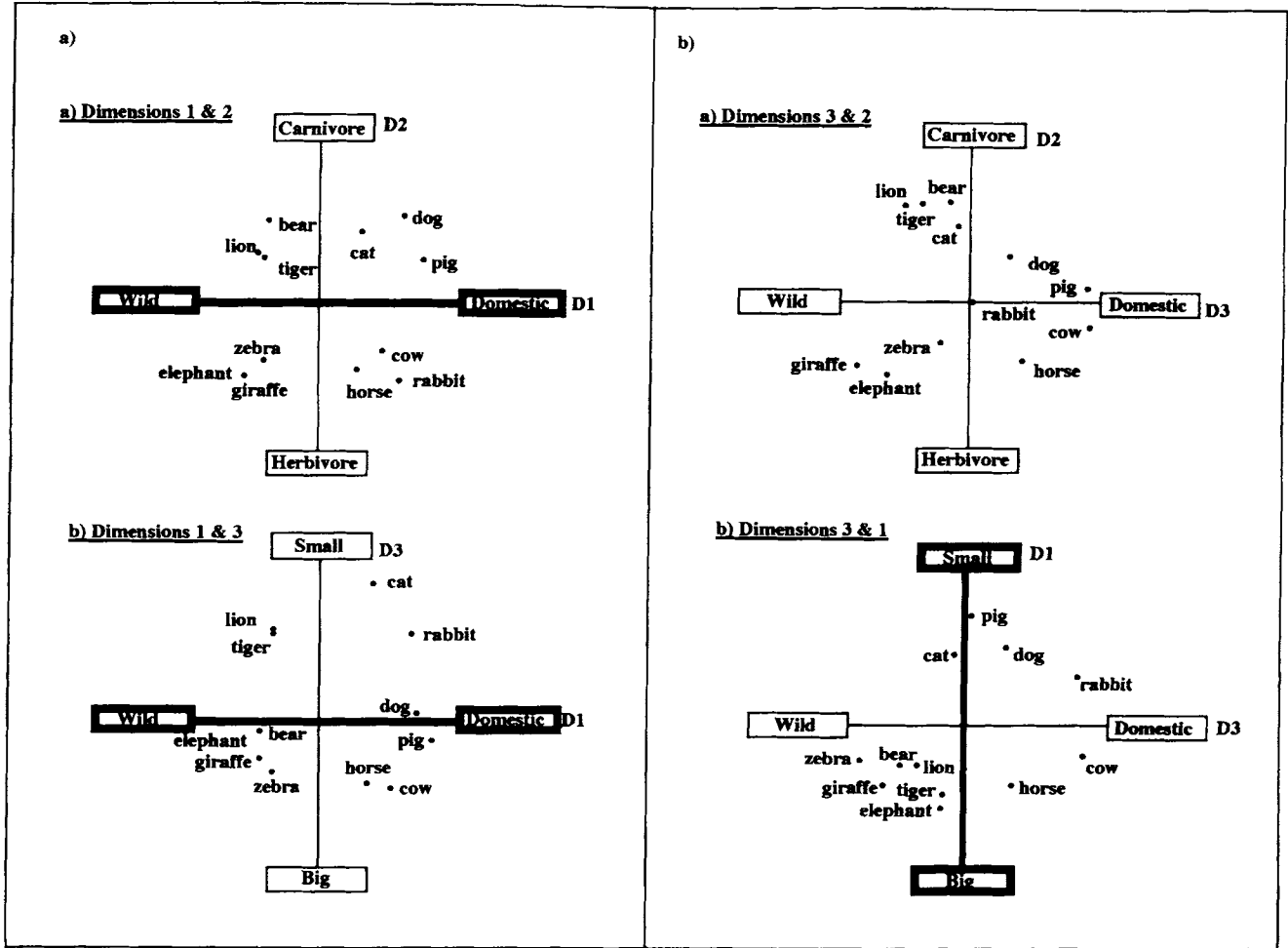


Figure 2. Cognitive maps of (a) 13 elderly normal controls and (b) 13 patients with Alzheimer's disease. Cognitive maps were generated by the Individual Difference Scaling Analysis based on the proximity data obtained from a triadic comparison task. The most salient dimension participants used in categorizing concepts is represented in bold outline (Chan et al., 1993).

attributes in categorizing concepts. Age as a significant factor for categorization has been discussed in detail by other investigators (see Markman, 1989, for general review).

*Pathfinder Analyses for the Semantic Networks of the Five Participant Groups*

Group semantic networks of MNC, HD, amnesic, ENC, and AD participants were computed by averaging the proximity

Table 3  
Participant Weights ( $M \pm SD$ ) on Three Dimensions and Skewness Index

Weight	ENC	AD
Dimension		
1	0.59 ± 0.32	0.62 ± 0.16
2	0.55 ± 0.28	0.51 ± 0.16
3	0.18 ± 0.10	0.29 ± 0.09*
Skewness index	0.48 ± 0.19	0.25 ± 0.15*

Note. ENC = elderly normal controls; AD = Alzheimer's disease. \* $p < .01$ .

data of all participants within a group. That is, for every two concepts in the network an average proximity value was calculated based on each participant's proximity data. This procedure resulted in a  $12 \times 12$  matrix for each of the five participant groups. These matrices were then analyzed by Pathfinder analysis, resulting in one semantic network for each group of participants. The MNC participants' semantic network consisted of 31 links compared with 45 links for the HD patients and 35 for the amnesic participants. The 59 links in the group network of AD patients was considerably higher than the 40 links noted for the ENC group. Figure 3 shows two examples (ENC and AD) of semantic networks generated by the Pathfinder analyses.

Because the semantic networks of all patient groups were more complex (i.e., consisted of more links) than those of their corresponding control groups, they were further analyzed to determine the significance of this difference in terms of the strength of associations (i.e., the weight associated with each pair of concepts) and the number of common links (i.e., the links that exist in both networks).

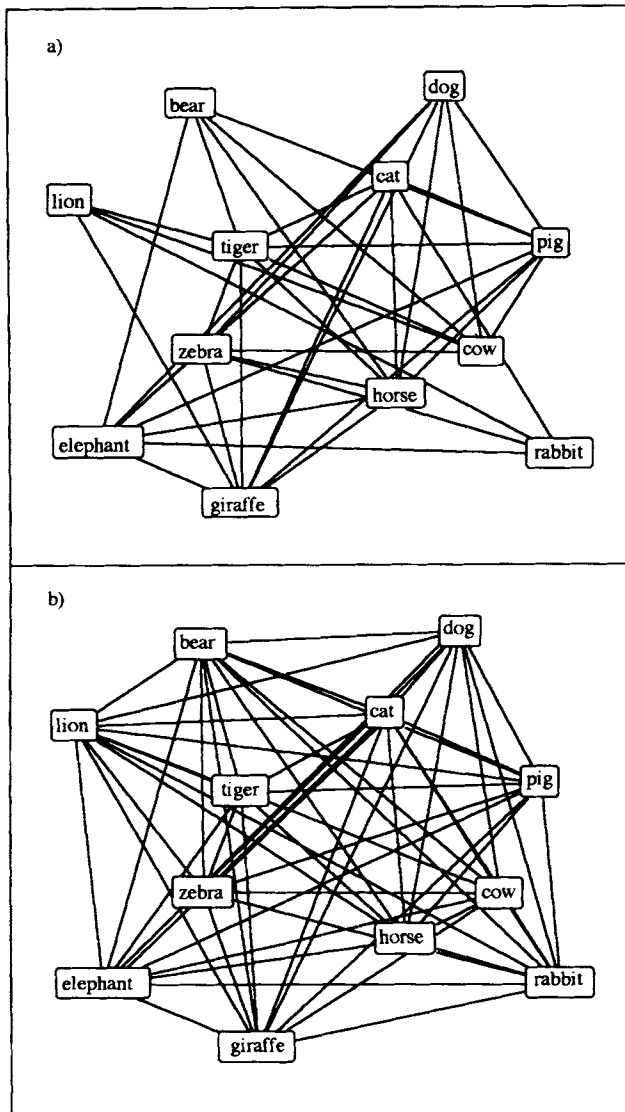


Figure 3. Semantic networks of (a) 13 elderly normal controls and (b) 13 patients with Alzheimer's disease generated by Pathfinder analysis.

**Strength of associations.** With  $r$  set to 1, each network generated was the most detailed model that can be obtained from a particular set of proximity data. As mentioned in the Method section, each network generated by Pathfinder analysis consists of many interconnected nodes, with each node representing one of the concepts comprising the network. Each connection represents the strength of the association between two concepts. To evaluate the integrity of the semantic networks of the three patient groups, we compared the group semantic networks of HD and amnesic participants with that of their age-matched controls (i.e., MNC participants), and the group semantic network of AD patients was compared with that of ENC participants.

Figure 4A shows that the correlation between the weights of each pair of concepts (e.g., *dog* and *bear*) in the semantic networks of the MNC and HD participants was significant,

$F(1, 64) = 21.0, p < .01; r = .50, r^2 = .25$ . The same analysis was applied to compare the group semantic network of MNC participants with that of amnesic patients. The results revealed that the strength of the associations in the group semantic network of MNC participants was significantly correlated with that of the amnesic patients,  $F(1, 64) = 122.3, p < .01; r = .81, r^2 = .66$  (see Figure 4B). However, while the semantic networks of HD and amnesic patients were significantly correlated with that of the MNC participants, the group semantic network of AD patients was not significantly correlated with that of the ENC participants,  $F(1, 64) = .047, ns; r = .027, r^2 = .001$  (see Figure 4C).

To evaluate the effect of age on the strength of associations, we compared the semantic networks of MNC and ENC participants. The semantic networks of normal individuals regardless of age have similar strength of associations as indicated by the significant correlation,  $F(1, 64) = 44.0, p < .01; r = .64, r^2 = .41$  (see Figure 4D).

Because these correlational findings may have been distorted by the unequal numbers of connections within each group (see Figure 4), further analyses were conducted. As shown in Figure 4, the unequal numbers of links are due to the large number of the control associations that have a strength value of 0. To determine whether these unequal numbers of links did influence the reported correlations, additional analyses were performed excluding all links with a value of 0 for either patients or controls. Despite these exclusions, the general direction of the results remained the same. The correlation between the networks of HD and MNC participants increased from .50 to .90,  $F(1, 29) = 119.0, p < .01$ . The strength of the associations in the semantic network of the MNC participants remained highly correlated with those in the network of the amnesic patients,  $F(1, 29) = 425.1, p < .01; r = .97, r^2 = .94$ . The correlation between the semantic networks of AD and ENC participants was again not significant,  $F(1, 35) = 2.98, ns; r = .28, r^2 = .08$ . These results indicate that the semantic networks of AD patients, but not those of HD and amnesic patients, contain atypical strength of associations as compared with those of their age-matched individuals.

**Common links.** The complexity of the semantic networks of the five participant groups was also examined by calculating the number of shared links in the networks of each patient group and their age-matched counterparts. Pathfinder analysis was used to derive a standard network for the MNC participants based on the averaged data of this group. The semantic network of each HD patient was then compared with the standard network of the MNC group. A similarity index was calculated based on the method suggested by Goldsmith and Davenport (1990) for each HD patient. This index was calculated by correlating the number of common links between a patient's semantic network and the standard MNC network, and the significance of the correlation was determined by a probability value (i.e.,  $p$  value). This similarity index ranges from 0 to 1, with 0 indicating two completely different networks and 1 indicating two identical networks. Averaging the similarity indices of all HD patients' semantic networks yielded a mean similarity index of 0.61 ( $SD = 0.85$ ), and the mean probability of all the correlations was less than .001. These results showed that the semantic networks of all HD

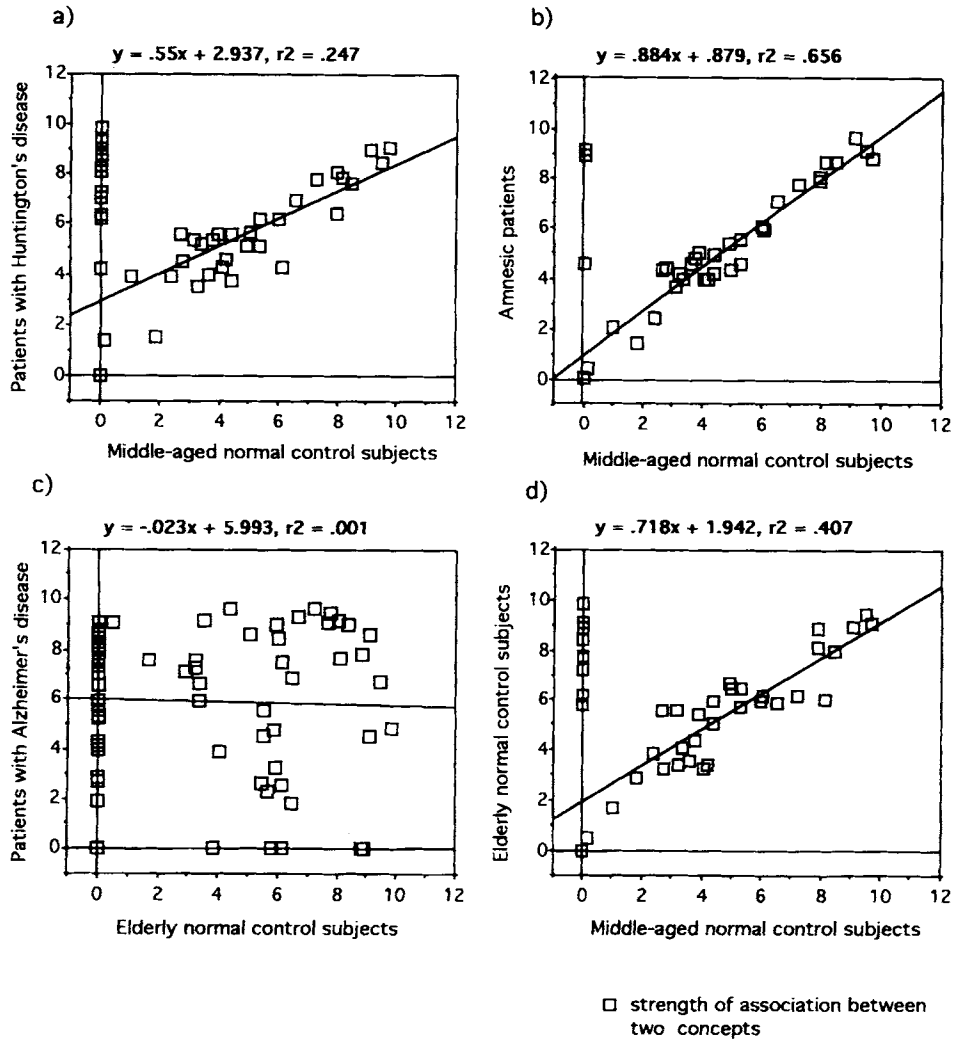


Figure 4. Four correlational analyses of the strength of the associations in the semantic networks of patients with Huntington's disease, amnesia, and Alzheimer's disease with elderly and middle-aged normal controls. Analyses were based on the weights of the 120 pairs of concepts in each semantic network. Each point on a map represents a pair of concepts, and the position of each point was determined by the weights of the pair of concepts in the two networks.

patients correlated significantly with the standard MNC network as their  $p$  values were less than .05.

The group semantic network of the MNC participants was compared with the semantic networks of amnesic patients by using the same analyses. The mean similarity index of the semantic networks of amnesic patients, as compared with the standard network generated from the average data of MNC participants, was 0.65 ( $SD = 0.039$ ). The  $p$  values of all semantic networks were less than .001. These results showed that the semantic networks of all amnesic patients were significantly correlated with that of the MNC group.

The comparison of AD and ENC amnesic participants revealed a different pattern than did the comparisons of MNC participants to HD and amnesic patients. The number of common links in the semantic networks of AD patients was not significantly correlated with that of the standard ENC network

as indicated by the low mean similarity index of AD ( $M = 0.38$ ;  $SD = 0.093$ ) and all the  $p$  values were greater than .05 (range .23–.98).

## Discussion

The present findings with INDSCAL indicate that HD and amnesic patients can generate cognitive maps similar to those of their age-matched controls. Both the HD and amnesic patients, like the MNC participants, relied primarily on the abstract dimension of *domesticity* when categorizing animal names on the triadic comparison task. In contrast, the AD patients stressed the concrete perceptual dimension of *size* for organizing animals on this comparison task and produced cognitive maps that differed from those of the ENC participants who also used the dimension of *domesticity* (Chan et al.,

1993). This difference in the performance of HD and AD patients suggests that a general retrieval deficit is not sufficient to distort the cognitive map and that deterioration of the structure of semantic knowledge is not a necessary characteristic of all forms of dementia. Similarly, the relatively normal semantic networks of severely amnesic patients indicates that the disruption of semantic networks noted in AD patients cannot be attributed to their profound episodic memory disorder. Because AD, but not HD and amnesia, is characterized primarily by extensive atrophy of temporal and parietal association cortices (Katzman & Jackson, 1991), these findings provide support for the notion that the integrity of these cortical regions is necessary for maintaining the organization of semantic knowledge (McCarthy & Warrington, 1988; McCarthy & Warrington, 1990).

A major goal of this study was to use Pathfinder analysis to compare some of the features of the cognitive maps of the patients and their age-matched controls. The results show that the cognitive maps of the AD patients, when compared with those of the ENC participants, were characterized by atypical strength of associations and fewer common links. In contrast, HD and amnesic patients' semantic networks were similar to those of their controls in terms of these two quantitative features. Overall, like the INDSCAL findings the measures derived from the Pathfinder analysis indicate that the AD patients have suffered a far greater deterioration of their cognitive space than have HD and amnesic patients. Thus, the present results taken in conjunction with our previous studies (Chan, Butters, Paulsen, et al., 1993; Chan et al., 1993) indicate that the semantic networks of AD patients can be characterized by a shifting of the primary dimensions of categorization, an abnormal clustering of concepts, and the presence of more abnormal and fewer common (i.e., normal) associations.

It is evident from these results that AD patients rely heavily on concrete perceptual information for categorizing information. In addition, they are impaired in judging the similarities among concepts, and their strategies in grouping concepts are different from those of normal individuals. It should be noted that HD patients, whose level of dementia is comparable with that of the AD patients, have essentially the same strategies as normal individuals in categorizing concepts. Thus, the abnormality demonstrated by AD patients on the triadic comparison task cannot be attributed to general factors, such as global dementia or the difficulty of the triadic comparison task.

These noted abnormalities in the AD patients' semantic networks are of special importance in understanding the organization of semantic knowledge. A study of a group of U.S. Air Force pilots with different levels of experience suggested that the status of a person's semantic network is a function of his possessed knowledge (Schvaneveldt et al., 1985). That is, an expert's ability to identify critical associations results in an orderly network with only essential links, a novice's inexperience in evaluating the relative importance of associations yields an entangled network consisting of many unnecessary connections. If the status of individuals' semantic networks is related to their level of possessed information, then neurologically impaired (e.g., Alzheimer's disease) patients who have a loss of semantic knowledge should produce networks that are

deviant (i.e., less common links and more atypical associations) in comparison to those of intact individuals. Then it appears that studies of both intact individuals and neurologically impaired patients suggest that the quantitative indices of strength of associations and of common links are important for evaluating the integrity and organization of semantic structure.

Although the abnormal semantic networks reported in the present study are consistent with many studies of the fate of AD patients' semantic knowledge (Abeyasinghe, Bayles, & Trosset, 1990; Chertkow & Bub, 1990; Eustache, Cox, Brandt, Lechevalier, & Pons, 1990; Grober, Buschke, Kawas, & Fuld, 1985; Martin & Fedio, 1983), the results appear to be inconsistent with the conclusions of several priming studies that used reaction times to assess the fate of semantic knowledge in AD (Nebes, 1989; Nebes & Brady, 1988; Nebes, Martin, & Horn, 1984). Nebes and colleagues (Nebes et al., 1984; Nebes & Brady, 1988) studied the semantic networks of AD patients by examining the difference between the reaction times of primed and nonprimed words. Given that both AD and normal controls identified or named a word (e.g., clothing) more quickly when it was preceded by a semantically related (e.g., shirt) rather than a semantically unrelated word (e.g., guide), these investigators have suggested that AD patients' semantic networks are relatively intact and comprised of associations of normal strength. They attributed AD patients' deficits on tests of semantic memory to a general failure in retrieval and the accessing of stored information.

The inconsistency between the present findings and those of Nebes and colleagues (Nebes et al., 1984; Nebes & Brady, 1988) may be attributable to the difference in the stimuli used in these two investigations. Whereas Nebes and his colleagues compared the strength of the associations between highly related concepts (e.g., hammer–nail) and totally unrelated pairs (e.g., star–song), we examined the relative associations among 12 within-category exemplars that all share some common attributes (e.g., four legs–land animals). Thus, if one assumes that a consequence of the structural alteration is a change in the saliency of attributes, then the strength of the associations between concepts that share several common attributes may be affected to a greater extent than those that share only a few attributes. Thus, a comparison focusing only on the relative associations between highly related and unrelated concepts may not be sensitive enough to detect subtle changes in the semantic networks of early-stage AD patients.

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